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Selection and Designing of Six Sigma Tightened – Normal - Tightened Variables Sampling Scheme (SSTNTVSS (n_T, n_N; k)) Indexed by Six Sigma AQL and Six Sigma AOQL

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Abstract
This article gives selection and designing of Six Sigma Tightened- Normal – Tightened Variables Sampling Scheme (SSTNTVSS (n_T, n_N; k)) indexed by Six Sigma AQL and Six Sigma AOQL. The procedure of designing and constructed tables for easy selection of system given by six sigma quality levels by known and unknown σ at Six Sigma levels.

Keywords
Tightened- Normal – Tightened Scheme, Variables Sampling, Six Sigma AOQ, Six Sigma AQL and Six Sigma AOQL.

INTRODUCTION

AOQ is widely used for the evaluation of a rectifying sampling plan. The average outgoing quality is the quality in the lot that results from the application of rectifying inspection. It is the average value of lot quality that would be obtained over a long sequence of lots from a process with fraction defective p. The maximum ordinate on the AOQ curve represents the worst possible average quality that would results from the rectifying inspection program, and this point is called the average outgoing quality limit (AOQL). The AOQL of rectifying inspection plan is a very important characteristic. It is possible to design rectifying inspection programs that have specified value of AOQL. The condition for application above basic assumptions of SSTNTVSS (n_T, n_N; k) scheme are the same as that of the SSTNTVSS (n; k_T, k_N) scheme.

The fraction defective in a lot will be

$p= 1-F(v)=F(-v)$ with $v=(U-\mu)/\sigma$ and

$$F(y) = \int_{-\infty}^{y} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz \qquad (1)$$

where z ~ N (0,1). Under the σ- method plan, the lot would be accepted if $\bar{X} + k\sigma \leq U$, where U is the upper specification limit or $\bar{X} + k\sigma \geq L$, where L is the lower specification limit.

Operating Procedure

Step 1: Inspect under tightened inspection using the single sampling plan with sample size $n_{T\sigma}$ and the acceptance constant k. Accept the individual lot. If $\bar{X}_T + k\sigma \leq U$ or $\bar{X}_T - k\sigma \geq L$ where $\bar{X}$ is the sample mean. If t lots in a row are accepted, switch to normal inspection (Step 2).

Step 2: Inspect under normal inspection using the single sampling plan with sample size $n_{N\sigma}$ ($<n_{T\sigma}$) and the acceptance constant k. Reject the individual lot. If $\overline{X}_N + k\sigma > U$ or $\overline{X}_N - k\sigma < L$ where $\overline{X}$ is the sample mean. When an additional lot is rejected in the next s lots after a rejection, switch to tightened inspection.

where $\overline{X}_T = \frac{1}{n_T}\sum_{i=1}^{n_T} X_i$, $\overline{X}_N = \frac{1}{n_N}\sum_{i=1}^{n_N} X_i$, and X_i is the measurement of the i^{th} unit.

Thus, the SSTNTVS scheme is specified by the parameters $n_{T\sigma}$, $n_{N\sigma}$, k, s and t, where n_σ and n_N are the sample size and k is the acceptance constant of the variables sampling plan under normal and tightened inspection respectively, t is the criterion for switching to normal inspection, and s is the criterion for switching to tightened inspection. The SSTNT scheme with variables sampling scheme is simply designated as SSTNTVSS ($n_{T\sigma}$, $n_{N\sigma}$; k).

When s =4 and t = 5, the OC function of the TNTVSS becomes the scheme OC function of MIL – STD – 105D that involves tightened and normal inspections was derived by Dodge (1965), Hald and Thyregod (1965) and Stephen and Larson (1967).

Operating Characteristic function

According to Calvin (1977), the OC function of the TNT scheme is given by

$$P_a(p) = \frac{P_T(1-P_N^s)(1-P_T^t)(1-P_N) + P_N P_T^t(1-P_T)(2-P_N^s)}{(1-P_N^s)(1-P_T^t)(1-P_N) + P_T^t(1-P_T)(2-P_N^s)} \qquad (2)$$

where P_T and P_N are the proportion of lots expected to be accepted using tightened ($n_{T\sigma}$, k) and normal ($n_{N\sigma}$, k) variables single sampling plans respectively. Under the assumption of normal distribution, the expression for P_T and P_N are given by

$$P_T = \Pr\,[(U-\overline{X})/\sigma \geq k] \qquad (3)$$

and $$P_N = P\,[(U-\overline{X})/\sigma \geq k] \qquad (4)$$

respectively. Equations (3) and (4) are substituted in (2) to find $P_a(p)$ values for given p, s, t, n_T, n_N and k. As the individual values of X follows normal distribution with mean μ and variance σ^2, the expressions given in (3) and (4) can be restated as

$$P_T = \int_{-\infty}^{w_T} \frac{1}{\sqrt{2\pi}} e^{(-z^2/2)}\, dz \quad \text{and} \quad P_N = \int_{-\infty}^{w_N} \frac{1}{\sqrt{2\pi}} e^{(-z^2/2)}\, dz$$

respectively, with

$$w_T = \sqrt{n_\sigma}(U-k\sigma-\mu)/\sigma = (v-k)\sqrt{n_\sigma} \quad w_N = \sqrt{n_\sigma}(U-k\sigma-\mu)/\sigma = (v-k)\sqrt{n_\sigma} \quad \text{and} \quad v = (U-\mu)/\sigma$$

SSTNTVSS ($n_{T\sigma}$, $n_{N\sigma}$; k_σ) with known σ variables plan as the reference plan

The Six Sigma Tightened – Normal – Tightened Variables Sampling Scheme with known σ variables plan as the reference plan has following operating procedure

Variable Sampling Plan and SSAOQL procedures

If the quality of the accepted lot is p and all defective units found in the rejected lots are replaced by non-defective units in a rectifying inspection plan, the Six Sigma average outgoing quality (SSAOQ) can be approximated as

$$SSAOQ = pP_a(p) \qquad (5)$$

Where $P_a(p)$is defined in the equation (2). If p_m is the proportion nonconforming items at which SSAOQ is maximum, one has

$$SSAOQL = p_m P_a(p_m) \qquad (6)$$

If SSAQL (p_1) is prescribed, then the corresponding value of v_{SSAQL} or v_1 will be fixed and if $P_a(p)$ is fixed at 99.99966%, that is (1-α). Where, α = 0.0000034x10^{-6}. Hence we have

$$P_a(p_1) = (1-\alpha)$$

which is obtained from equation (2), and v_1 satisfies $w_N = (v_1 - k_\sigma)\sqrt{n_{N\sigma}}$ and $w_T = (v_1 - k_\sigma)\sqrt{n_{T\sigma}}$ (7)

So that for given values of n_σ, w_N, w_T and SSAQL, $k_{N\sigma}$, $k_{T\sigma}$ are determined.

Selection of known σ SSTNTVSS($n_{T\sigma}$, $n_{N\sigma}$; k_σ) for given SSAQL and SSAOQL

Table 1 is used for selection of σ- method SSTNTVSS. For example, if the SSAQL is fixed at p_1=0.00006 and the SSAOQL is fixed at 0.00007 and m=2, Table 1 yields $n_{N\sigma}$ = 2708, and k_σ = 3.92, which is associated with 4.5 sigma level of SSTNTVSS ($n_{T\sigma}$, $n_{N\sigma}$; k_σ). The sample size is $n_{T\sigma}$ = m $n_{N\sigma}$ = (2) (2708)=5416. Thus, for the given requirement, the SSTNTVSS ($n_{T\sigma}$, $n_{N\sigma}$; k_σ) is specified by the parameters $n_{T\sigma}$=5416, $n_{N\sigma}$=2708, and k_σ=3.921 with 4.5 sigma level.

The user of Table 1 should understand the limitations of plans indexed by SSAOQL. Sampling with rectifying of rejected lots on the one hand reduces the average percentage of nonconforming items in the lots, but on the other hand introduces non-homogeneity in the series of lots finally accepted. That is, any particular lot will have a quality of p% or 0% nonconforming depending on whether the lot is accepted or rectified. Thus the assumption underlying the SSAOQL principle is that the homogeneity in the qualities of individual lots is unimportant and only the average quality matters. For plans listed in Table 1, if the individual lot quality happens to be the product quality p_m at which SSAOQL occurs, then the associated probability of acceptance will be poor. Table 2 gives $P_a(p_m)$ values of plans given in Table 1. For example, for SSAQL of p_1=0.00005 and SSAOQL = 0.0001, Table 2 gives $P_a(p_m)$ = 0.69. Then p_m = SSAOQL/ $P_a(p_m)$ = 0.00015. In order to avoid such inconvenience, the producer should maintain the process quality more or less at the SSAQL. The high rate of rejection of lots at $p = p_m$ will also indirectly put pressure on the producer to improve the submitted quality.

SSTNTVSS with unknown σ variables plan as the reference plan

If the population standard deviation σ is unknown, it is estimated from the sample standard deviation S (n-1 in the division). If the sample size of the unknown sigma variables scheme (S – method) is n_{Ts} under tightened inspection and n_{Ns} under normal inspection and the acceptance constant is k, then the operating procedure is as follows:

Step 1: Inspect under tightened inspection using the single sampling plan with sample size n_{Ts} and the acceptance constant k. Accept the individual lot. If $\bar{X}_T + k\,S_T \le U$ or $\bar{X}_T - k\,S_T \ge L$ where $\bar{X}$ is a sample mean sample standard deviation S. If t lots in a row are accepted, switch to normal inspection (Step 2).

Step 2: Inspect under normal inspection using the single sampling plan with sample size n_{Ns} and the acceptance constant k_N. Reject the individual lot if $\bar{X}_N + k\,S_N > U$ or $\bar{X}_N - k\,S_N < L$ where $\bar{X}$ is a sample mean and sample standard deviation S. When an additional lot is rejected in the next s lots after a rejection, switch to tightened inspection.

Here $\bar{X}$ and S are the average and the standard deviation of quality characteristic respectively from the sample. Under the assumptions for SSTNTVSS stated, the probability of acceptance $P_a(p)$ of a lot is given in the equation (2) and P_T and P_N respectively are with

$$w_T = \frac{U-k\,S_T-\mu}{S_T} \quad \frac{1}{\sqrt{\left(\frac{1}{n_{Ts}}+\frac{k^2}{2n_{Ts}}\right)}} \quad \text{and} \quad w_N = \frac{U-k\,S_N-\mu}{S_N} \quad \frac{1}{\sqrt{\left(\frac{1}{n_{Ns}}+\frac{k^2}{2n_{Ns}}\right)}}$$

Selection of unknown σ SSTNTVSS($n_{T\sigma}$, $n_{N\sigma}$; k_σ) for given SSAQL and SSAOQL

Table 1 also gives such matched S-method plan. For example, for given SSAQL of p_1=0.00007 and SSAOQL = 0.0001, m = 2, one obtains the parameters of the S-method plan from Table 1 to be n_{Ns} = 2509, and k_s = 3.808 which is associated with 4.8 sigma level of SSTNTVSS($n_{T\sigma}$, $n_{N\sigma}$; k_σ). The sample size is $n_{T\sigma}$ = m $n_{N\sigma}$ = (2) (6836)=13672. Thus, for the given requirement, the SSTNTVSS($n_{T\sigma}$, $n_{N\sigma}$; k_σ) is specified by the parameters $n_{T\sigma}$=13672, $n_{N\sigma}$=6836, and k_σ=3.808 with 4.8 sigma level.

Construction of Table 1 & 2

For constructing Table 9.4, a trial value of p_m is assumed and the probability of acceptance at p_m is found using (6) as

$$P_a(p_m) = \text{SSAOQL} / p_m \qquad (8)$$

The auxiliary variables v_m, w_{Nm} and w_{Tm} corresponding to the values of p_m and $P_a(p_m)$ respectively, are found using (1) to (4). For given values of p_1, determine the values of v_1, w_N and w_T using the approximation (Abramwitz and Stegun (1972)) for the ordinate of the cumulative normal distribution. With the values of v_m, w_{Nm} and w_{Tm}, the following equations are derived, which Muthuraj and Senthilkumar(2006) used for calculating n_σ.

$$\sqrt{n_\sigma} = (-\text{AOQL}) / (p_m^2 (P_{T_1}^{'} G + P_N^{'} H) / (A+B)^2 \qquad (9)$$

where

$$P'_{T_1} = -\sqrt{(\exp(v_m^2 - w_{Tm}^2)} \quad (10)$$

$$P'_{N_1} = -\sqrt{(\exp(v_m^2 - w_{Nm}^2)} \quad (11)$$

Equation (9) is the formula for finding the sample size of a known σ SSTNT Variables Sampling Scheme. With the values of n_σ obtained from (9), it is then checked to see whether the assumed value of p_m corresponds to the proportion non-conforming at which the SSAOQL occurs or not. That is, it is checked to see whether or not the trial value of p_m satisfies the following condition.

$$AOQL + [(p_m^2(P'_{T_1}G + P'_N H) / (A+B)^2] = 0 \quad (12)$$

where $$P'_{T_1} = -\sqrt{n_{T_\sigma}\exp(v_m^2 - w_{Tm}^2)} = P'_{T_1} = -\sqrt{mn_{N_\sigma}\exp(v_m^2 - w_{Tm}^2)} \quad (13)$$

$$P'_{N_1} = -\sqrt{n_{N_\sigma}\exp(v_m^2 - w_{Nm}^2)} \quad (14)$$

The equation (12) was obtained from the following relation

$$\frac{d(SSAOQ)}{dp} = P_a(p) + p\frac{dP_a(p)}{dp} = 0 \quad (15)$$

in which

$$\frac{d(SSAOQ)}{dp} = \frac{P'_T\ G + P'_N\ H}{(A+B)^2} \quad (16)$$

If assumed value of p_m does not satisfy (12), then another trial value of p_m is obtained from (12) by numerical methods. The methods of successive substation is often found to give good results and (12) is rewritten for this purpose as

$$p_m = (-AOQL)/[p_m(P'_T G + P'_N H)/(A+B)^2] \quad (17)$$

After determining the next trial value of p_m, again the values of v_m, w_{Nm}, w_{Tm} and n_σ are found and the condition (12) rechecked. This iterative procedure continues until the convergence of p_m is achieved. Then the value of k_σ is obtained from (3) and (4).

For obtaining the values of v_1, w_N and w_T, the approximation for the ordinate of the cumulative normal distribution available in Abramowitz and Stegun (1972) was used.

The S-method plans matching the σ-method plans were obtained using computer search routine through C++ programme. For selected combinations of SSAQL and SSAOQL, Table 1 &2 was constructed following the above iterative procedure.

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Table 1: SSQSVSS with known and unknown σ indexed by SSAQL and SSAOQL ($n_{T\sigma} = mn_{N\sigma}$, where m=2)

SSAQL(p_1)	SSAOQL	$n_{T\sigma}$	$n_{N\sigma}$	k_σ	σ - Level	n_{Ts}	n_{Ns}	k_s	σ - Level
0.00001	0.00002	3781	1890	4.313	4.3	38948	19474	4.313	5.0
	0.00003	2429	1214	4.300	4.2	24884	12442	4.300	4.9
	0.00004	2158	1079	4.285	4.2	21967	10983	4.285	4.9
	0.00005	1824	912	4.273	4.1	18477	9238	4.273	4.8
	0.00006	1459	730	4.262	4.0	14710	7355	4.262	4.7
	0.00007	1063	532	4.247	3.9	10650	5325	4.247	4.7
	0.00008	636	318	4.232	3.7	6330	3165	4.232	4.5
	0.00009	610	305	4.219	3.7	6035	3018	4.219	4.5
	0.0001	583	292	4.204	3.7	5737	2869	4.204	4.5
	0.0002	521	260	4.189	3.6	5090	2545	4.189	4.4
	0.0003	468	234	4.174	3.6	4545	2273	4.174	4.4
0.00002	0.00003	3556	1778	4.306	4.3	36529	18265	4.306	5.0
	0.00004	3154	1577	4.230	4.3	31373	15686	4.230	5.0
	0.00005	2659	1330	4.215	4.2	26281	13141	4.215	4.9
	0.00006	1605	803	4.203	4.1	15781	7891	4.203	4.8
	0.00007	1170	585	4.191	3.9	11442	5721	4.191	4.7
	0.00008	700	350	4.176	3.8	6800	3400	4.176	4.5
	0.00009	671	335	4.161	3.7	6476	3238	4.161	4.5
	0.0001	642	321	4.148	3.7	6162	3081	4.149	4.5
	0.0002	573	286	4.133	3.7	5466	2733	4.133	4.5
	0.0003	515	257	4.118	3.6	4880	2440	4.118	4.4
	0.0004	459	230	4.103	3.6	4326	2163	4.103	4.4
0.00003	0.00004	8516	4258	4.236	4.6	84919	42460	4.236	5.2
	0.00005	3058	1529	4.160	4.3	29517	14758	4.160	4.9
	0.00006	1846	923	4.145	4.1	17699	8850	4.145	4.8
	0.00007	1345	672	4.132	4.0	12828	6414	4.132	4.7
	0.00008	805	402	4.121	3.8	7635	3817	4.121	4.6
	0.00009	771	386	4.105	3.8	7270	3635	4.106	4.6
	0.0001	738	369	4.090	3.8	6909	3454	4.090	4.5
	0.0002	659	329	4.078	3.7	6136	3068	4.078	4.5
	0.0003	592	296	4.062	3.7	5477	2738	4.062	4.5

	0.0004	528	264	4.047	3.7	4854	2427	4.047	4.4
	0.0005	428	214	4.033	3.6	3909	1955	4.033	4.4

Table 1 (continued…)

SSAQL(p_1)	SSAOQL	$n_{T\sigma}$	$n_{N\sigma}$	k_σ	σ - Level	n_{Ts}	n_{Ns}	k_s	σ - Level
0.00004	0.00005	10475	5237	4.090	4.7	98071	49036	4.090	5.3
	0.00006	3670	1835	4.074	4.3	34130	17065	4.074	5.0
	0.00007	2049	1024	4.062	4.2	18953	9476	4.062	4.8
	0.00008	1493	746	4.050	4.0	13738	6869	4.050	4.7
	0.00009	893	447	4.035	3.9	8163	4081	4.035	4.6
	0.0001	856	428	4.020	3.8	7771	3886	4.020	4.6
	0.0002	819	409	4.007	3.8	7392	3696	4.007	4.6
	0.0003	731	366	3.992	3.8	6557	3278	3.992	4.5
	0.0004	657	329	3.976	3.8	5852	2926	3.976	4.5
	0.0005	586	293	3.962	3.7	5189	2594	3.962	4.5
0.00005	0.00006	7532	3766	4.004	4.6	67894	33947	4.004	5.2
	0.00007	3494	1747	3.991	4.3	31321	15661	3.991	5.0
	0.00008	1851	926	3.979	4.1	16507	8254	3.979	4.8
	0.00009	1107	554	3.964	3.9	9807	4903	3.964	4.7
	0.0001	1061	531	3.950	3.9	9340	4670	3.950	4.6
	0.0002	1015	508	3.937	3.9	8883	4442	3.937	4.6
	0.0003	907	453	3.921	3.9	7878	3939	3.921	4.6
	0.0004	815	407	3.906	3.8	7030	3515	3.906	4.6
	0.0005	727	364	3.892	3.8	6233	3116	3.892	4.5
0.00006	0.00007	5416	2708	3.921	4.5	47042	23521	3.921	5.1
	0.00008	2125	1063	3.909	4.2	18360	9180	3.909	4.8
	0.00009	1273	637	3.893	4.0	10925	5463	3.893	4.7
	0.0001	1218	609	3.879	4.0	10385	5193	3.879	4.7
	0.0002	1166	583	3.866	4.0	9877	4938	3.866	4.7
	0.0003	1041	520	3.850	3.9	8758	4379	3.851	4.6
	0.0004	935	468	3.835	3.9	7814	3907	3.835	4.6
	0.0005	835	417	3.821	3.9	6927	3463	3.821	4.6
0.00007	0.00008	5015	2508	3.838	4.5	41954	20977	3.838	5.1
	0.00009	1732	866	3.822	4.1	14384	7192	3.822	4.8
	0.0001	1657	829	3.808	4.1	13672	6836	3.808	4.8
	0.0002	1585	793	3.795	4.1	13001	6500	3.795	4.7

	0.0003	1416	708	3.780	4.1	11532	5766	3.780	4.7
	0.0004	1272	636	3.765	4.0	10288	5144	3.765	4.7

Table 1 (continued…)

SSAQL(p_1)	SSAOQL	$n_{T\sigma}$	$n_{N\sigma}$	k_σ	σ - Level	n_{Ts}	n_{Ns}	k_s	σ - Level
0.00007	0.0005	1135	568	3.750	4.0	9118	4559	3.750	4.6
0.00008	0.00009	2754	1377	3.752	4.3	22140	11070	3.752	4.9
	0.0001	1842	921	3.738	4.1	14708	7354	3.738	4.8
	0.0002	1762	881	3.725	4.1	13984	6992	3.725	4.8
	0.0003	1574	787	3.710	4.1	12403	6201	3.710	4.7
	0.0004	1414	707	3.694	4.1	11063	5532	3.694	4.7
	0.0005	1262	631	3.680	4.0	9804	4902	3.680	4.7
0.00009	0.0001	2208	1104	3.667	4.2	17053	8526	3.667	4.8
	0.0002	1958	979	3.654	4.2	15025	7513	3.654	4.8
	0.0003	1748	874	3.639	4.1	13324	6662	3.639	4.8
	0.0004	1571	786	3.623	4.1	11883	5941	3.623	4.7
	0.0005	1402	701	3.609	4.1	10529	5264	3.609	4.7

Table 2: $P_a(p_m)$ Values of known σ plans

SSAOQL	SSAQL (p_1)								
	0.00001	0.00002	0.00003	0.00004	0.00005	0.00006	0.00007	0.00008	0.00009
0.00002	0.90								
0.00003	0.87	0.91							
0.00004	0.86	0.88	0.91						
0.00005	0.85	0.85	0.88	0.93					
0.00006	0.80	0.83	0.86	0.90	0.92				
0.00007	0.71	0.74	0.77	0.81	0.83	0.85			
0.00008	0.63	0.66	0.69	0.73	0.75	0.77	0.81		
0.00009	0.62	0.65	0.68	0.72	0.74	0.76	0.80	0.83	
0.0001	0.57	0.60	0.63	0.67	0.69	0.71	0.75	0.78	0.82
0.0002	0.51	0.54	0.57	0.61	0.63	0.65	0.69	0.72	0.76
0.0003	0.48	0.51	0.54	0.58	0.60	0.62	0.66	0.69	0.73
0.0004		0.48	0.51	0.56	0.57	0.60	0.63	0.67	0.70
0.0005			0.46	0.51	0.52	0.55	0.58	0.62	0.65